Longevity of turf response to Agrium AT slow and controlled release fertilizers - 2011

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The objective of this research project was to quantify turf response to a one-time application of coated urea fertilizers on Kentucky bluegrass turf on a soil rootzone.

Data collected included the duration and strength of the color response following application of the tested products, turf quality, uniformity, and density, and resistance of the turf to disease and other stresses.

MATERIALS / METHODS

The treatments consisted of the sponsor's products at specified rate and application program (Table 1). An unfertilized check treatment was also included. Treatments were applied to 1 x 3 m plots of Kentucky bluegrass turf maintained as a home-lawn type turf on the research ranges at the Guelph Turfgrass Institute (mowing at 40 mm, irrigation to prevent stress) (Figure 1). Treatments were replicated four times in a randomized complete block design. Treatments were applied July 4, 2011 according to the recommended programs.

Color response of the turf to treatments was assessed pre-treatment, and then on a weekly basis, both visually and using instrumental color (canopy reflectance – normalized-difference vegetation index using an Ntech Greenseeker). Uniformity of the color response was assessed visually using a scale of 1 to 9 (1=dead, 9=ideal, 5=acceptable). Plots were rated for turf quality, density and uniformity. Clippings were collected at 2, 4, 6, 8, 10, 12, 14, and 16 weeks after treatment, dried and weighed to determine shoot dry matter accumulation per unit area. Soil temperature at 5 cm depth was monitored with Spectrum WatchDog data loggers, and reported as daily mean. Other stresses were measured as they occurred (disease, weed, drought).

Spring greenup will be assessed in April 2012.

An anecdotal photographic record of the experiment was kept.

All measurements were analyzed by appropriate statistical analyses (general linear models).

RESULTS

Environmental data. Daily air and soil temperatures for June – October 2011 are presented in Figures 2 and 3.

Table 1. Treatments

Trt #	Description	Rate	
		lb. N / M	g N m^{-}
1	Untreated control	—	—
2	Urea 46-0-0, rate	1.00	4.88
3	ProTurf Turf N (Polyon) 44-0-0 SGN 250 rate	1.25	6.10
4	ProTurf Turf N (Polyon) 44-0-0 SGN 190 rate	1.25	6.10
5	Polyon 43-0-0 SGN 250 rate	1.75	8.54
6	Polyon 43-0-0 SGN 190 rate	1.75	8.54
7	Polyon 42-0-0 SGN 250 rate	2.00	9.76
8	XCU 43-0-0 SGN 260 rate	1.25	6.10
9	XCU 43-0-0 SGN 190 rate	1.25	6.10
10	ProTurf Turf N (Poly-S) 40-0-0 rate	1.25	6.10

Figure 1. Plot area July 27, 2011 (23 DAT).

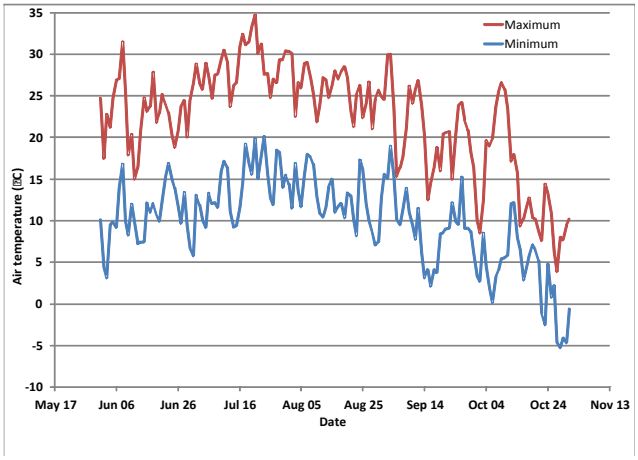

Figure 2. Daily air temperatures at GTI, summer 2011

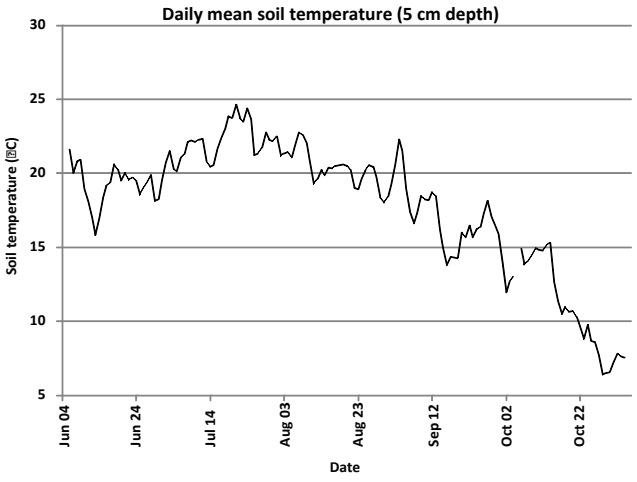

Figure 3. Daily soil temperatures at GTI, summer 2011

Visual ratings. There were significant differences in visual ratings of turf colour and quality by 7 DAT (Table 2). The differences in quality persisted until 7 weeks after treatment, but colour differences were no longer significant at this point. Other visual performance ratings (uniformity and density) generally did not differ significantly. All plots had acceptable levels of visual performance during the trial.

Table 2. Visual ratings of treated plots

Treatment	7 DAT	22 DAT	51 DAT	7 DAT	22 DAT	51 DAT
	Colour			Quality		
Polyon 42-0-0 SGN 250	6.50 cd	7.00 bc	8.50	6.25 ab	7.25 ab	8.00 a
Polyon 43-0-0 SGN 190	7.50 abc	8.50 a	8.25	7.00 a	7.25 ab	8.00 a
Polyon 43-0-0 SGN 250	7.00 bcd	8.25 a	8.50	6.75 ab	7.25 ab	8.00 a
ProTurf 40-0-0	8.25 a	8.00 ab	8.00	7.00 a	7.00 ab	8.00 a
ProTurf 44-0-0 SGN 190	7.25 abcd	8.00 ab	8.25	6.75 ab	7.25 ab	8.00 a
ProTurf 44-0-0 SGN 250	7.50 abc	7.50 abc	8.25	7.00 a	7.25 ab	8.00 a
Urea	8.00 ab	7.50 abc	8.25	7.00 a	7.00 ab	8.00 a
XCU 43-0-0 SGN 190	8.25 a	8.25 a	8.25	7.00 a	7.75 a	8.00 a
XCU 43-0-0 SGN 260	8.25 a	8.00 ab	8.25	6.75 ab	7.25 ab	8.00 a
Untreated control	6.25 d	6.75 c	7.25	6.00 b	6.75 b	7.25 b
msd p=0.05	1.08	1.06	NS	0.90	0.81	0.38
	Uniformity			Density		
Polyon 42-0-0 SGN 250	6.75	6.75	8.00	6.50	7.25	8.00
Polyon 43-0-0 SGN 190	6.75	7.00	8.00	6.50	7.75	8.00
Polyon 43-0-0 SGN 250	6.50	7.25	8.00	6.50	7.75	8.00
ProTurf 40-0-0	7.00	6.75	8.00	6.75	7.75	8.00
ProTurf 44-0-0 SGN 190	6.50	6.75	8.00	6.50	7.75	8.00
ProTurf 44-0-0 SGN 250	6.75	7.25	8.00	7.25	7.75	8.00
Urea	7.00	7.00	7.75	6.75	7.50	8.00
XCU 43-0-0 SGN 190	6.75	7.25	8.00	7.00	7.75	8.00
XCU 43-0-0 SGN 260	6.50	7.25	8.00	6.75	7.50	8.00
Untreated control	6.75	7.00	8.00	6.25	7.50	8.00
msd p=0.05	NS	NS	NS	NS	NS	NS

[1] Visual ratings 0-10, 10 = best, 6 = acceptable. Means of 4 replicates; means within columns followed by the same letter are not significantly different (Tukey's HSD test, p=0.05).

Canopy reflectance. The canopy reflectance (normalized-difference vegetation index) data collected with the Greenseeker gave a very precise picture of the response to the treatments. Index values were calculated both as the raw NDVI values and as values corrected by subtracting the value of the untreated control to remove background variation, since the NDVI value is affected by mowing, moisture status, and other factors in addition to nitrogen status. Figure 4 shows the pattern of change of the raw NDVI values (averaged across all plots) and the ΔNDVI values (averaged across all non-control plots) during the experiment.

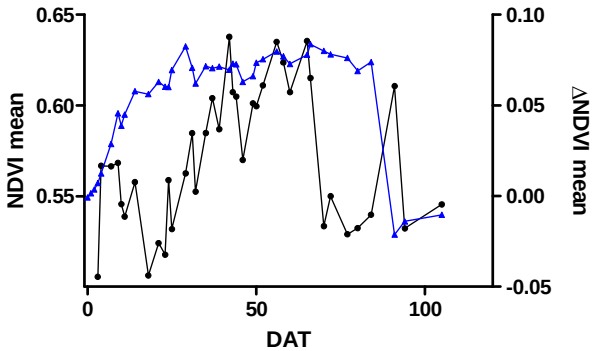

Figure 4. Changes in overall mean NDVI (black •) and ΔNDVI (corrected to remove control value; blue▲) during the experiment.

There were significant differences in canopy reflectance among the treatments beginning 4 DAT and lasting until the last measurement date (105 DAT) (Table 3). By 9 DAT all treatments with the exception of Polyon 42-0-0 SGN 250 had significantly larger canopy reflectance values than the untreated control. By 32 DAT all

Table 3. Canopy reflectance in treated plots

Treatment	DAT								
	-17	-14	-7	-5	0	1	2	3	4
Polyon 42-0-0 SGN 250	0.519	0.469	0.490	0.464	0.483	0.487	0.485	0.494	**0.545 b**
Polyon 43-0-0 SGN 190	0.504	0.451	0.489	0.466	0.480	0.481	0.481	0.497	**0.559 ab**
Polyon 43-0-0 SGN 250	0.524	0.472	0.501	0.477	0.501	0.499	0.495	0.509	**0.561 ab**
ProTurf 40-0-0	0.530	0.469	0.493	0.474	0.482	0.487	0.491	0.506	**0.571 ab**
ProTurf 44-0-0 SGN 190	0.521	0.465	0.492	0.472	0.486	0.486	0.482	0.498	**0.561 ab**
ProTurf 44-0-0 SGN 250	0.513	0.463	0.498	0.467	0.494	0.491	0.492	0.508	**0.570 ab**
Urea	0.521	0.461	0.491	0.471	0.490	0.491	0.494	0.520	**0.589 a**
XCU 43-0-0 SGN 190	0.531	0.478	0.502	0.487	0.499	0.503	0.501	0.515	**0.583 a**
XCU 43-0-0 SGN 260	0.503	0.444	0.494	0.465	0.496	0.490	0.490	0.510	**0.576 ab**
Untreated control	0.513	0.456	0.486	0.479	0.492	0.489	0.487	0.499	**0.554 ab**
msd p=0.05	NS	NS	NS	NS	NS	NS	NS	NS	**0.036**
	7	**9**	**10**	**11**	**14**	**18**	**21**	**23**	**24**
Polyon 42-0-0 SGN 250	**0.530 d**	**0.525 c**	**0.508 b**	**0.490 b**	**0.520 b**	**0.464 bc**	**0.486 bc**	**0.484 bc**	**0.529 ab**
Polyon 43-0-0 SGN 190	**0.554 bcd**	**0.560 b**	**0.540 ab**	**0.541 a**	**0.596 a**	**0.516 abc**	**0.536 ab**	**0.534 ab**	**0.581 a**
Polyon 43-0-0 SGN 250	**0.563 abcd**	**0.559 b**	**0.538 ab**	**0.538 a**	**0.579 ab**	**0.506 abc**	**0.529 abc**	**0.524 ab**	**0.569 a**
ProTurf 40-0-0	**0.586 ab**	**0.582 ab**	**0.559 a**	**0.548 a**	**0.584 ab**	**0.502 abc**	**0.514 abc**	**0.511 abc**	**0.551 ab**
ProTurf 44-0-0 SGN 190	**0.570 abc**	**0.580 ab**	**0.552 a**	**0.553 a**	**0.594 a**	**0.509 abc**	**0.538 ab**	**0.520 abc**	**0.565 a**
ProTurf 44-0-0 SGN 250	**0.566 abc**	**0.578 ab**	**0.558 a**	**0.553 a**	**0.623 a**	**0.539 a**	**0.563 a**	**0.550 a**	**0.585 a**
Urea	**0.591 a**	**0.596 a**	**0.569 a**	**0.561 a**	**0.607 a**	**0.522 ab**	**0.539 ab**	**0.529 ab**	**0.570 a**
XCU 43-0-0 SGN 190	**0.586 ab**	**0.592 a**	**0.570 a**	**0.559 a**	**0.613 a**	**0.526 ab**	**0.537 ab**	**0.532 ab**	**0.566 a**
XCU 43-0-0 SGN 260	**0.587 ab**	**0.585 ab**	**0.564 a**	**0.553 a**	**0.620 a**	**0.528 ab**	**0.543 ab**	**0.535 ab**	**0.578 a**
Untreated control	**0.538 cd**	**0.522 c**	**0.507 b**	**0.494 b**	**0.518 b**	**0.450 c**	**0.461 c**	**0.457 c**	**0.498 b**
msd p=0.05	**0.035**	**0.031**	**0.035**	**0.036**	**0.069**	**0.068**	**0.073**	**0.065**	**0.064**
	25	**29**	**31**	**32**	**35**	**37**	**39**	**42**	**43**
Polyon 42-0-0 SGN 250	**0.504 ab**	**0.544 ab**	**0.579 ab**	**0.539 a**	**0.578 a**	**0.604 a**	**0.593 a**	**0.631 a**	**0.621 a**
Polyon 43-0-0 SGN 190	**0.557 a**	**0.598 a**	**0.628 a**	**0.577 a**	**0.612 a**	**0.635 a**	**0.613 a**	**0.671 a**	**0.635 a**
Polyon 43-0-0 SGN 250	**0.545 a**	**0.585 a**	**0.620 a**	**0.570 a**	**0.605 a**	**0.629 a**	**0.611 a**	**0.676 a**	**0.627 a**
ProTurf 40-0-0	**0.522 ab**	**0.555 a**	**0.590 a**	**0.550 a**	**0.582 a**	**0.605 a**	**0.582 a**	**0.634 a**	**0.605 a**
ProTurf 44-0-0 SGN 190	**0.537 a**	**0.565 a**	**0.609 a**	**0.552 a**	**0.597 a**	**0.609 a**	**0.597 a**	**0.646 a**	**0.614 a**
ProTurf 44-0-0 SGN 250	**0.562 a**	**0.591 a**	**0.632 a**	**0.570 a**	**0.595 a**	**0.615 a**	**0.598 a**	**0.642 a**	**0.618 a**
Urea	**0.538 a**	**0.568 a**	**0.606 a**	**0.553 a**	**0.582 a**	**0.600 a**	**0.590 a**	**0.650 a**	**0.605 a**
XCU 43-0-0 SGN 190	**0.543 a**	**0.572 a**	**0.609 a**	**0.560 a**	**0.589 a**	**0.602 a**	**0.584 a**	**0.626 a**	**0.604 a**
XCU 43-0-0 SGN 260	**0.550 a**	**0.573 a**	**0.606 a**	**0.562 a**	**0.595 a**	**0.607 a**	**0.589 a**	**0.633 a**	**0.610 a**
Untreated control	**0.462 b**	**0.480 b**	**0.519 b**	**0.491 b**	**0.514 b**	**0.533 b**	**0.514 b**	**0.569 b**	**0.533 b**
msd p=0.05	**0.063**	**0.065**	**0.061**	**0.044**	**0.040**	**0.037**	**0.041**	**0.054**	**0.044**
	44	**46**	**49**	**50**	**52**	**56**	**58**	**60**	**65**
Polyon 42-0-0 SGN 250	**0.628 a**	**0.593 a**	**0.623 a**	**0.635 a**	**0.646 a**	**0.678 a**	**0.680 a**	**0.654 a**	**0.683 a**
Polyon 43-0-0 SGN 190	**0.636 a**	**0.598 a**	**0.632 a**	**0.630 ab**	**0.645 a**	**0.667 a**	**0.662 a**	**0.636 ab**	**0.665 ab**
Polyon 43-0-0 SGN 250	**0.638 a**	**0.595 a**	**0.628 a**	**0.622 ab**	**0.637 a**	**0.665 a**	**0.659 a**	**0.631 ab**	**0.666 ab**
ProTurf 40-0-0	**0.609 a**	**0.569 a**	**0.600 a**	**0.601 ab**	**0.607 a**	**0.633 a**	**0.630 a**	**0.605 ab**	**0.637 ab**
ProTurf 44-0-0 SGN 190	**0.630 a**	**0.574 a**	**0.606 a**	**0.612 ab**	**0.618 a**	**0.643 a**	**0.645 a**	**0.613 ab**	**0.643 ab**
ProTurf 44-0-0 SGN 250	**0.627 a**	**0.575 a**	**0.604 a**	**0.599 ab**	**0.613 a**	**0.630 a**	**0.630 a**	**0.606 ab**	**0.632 ab**
Urea	**0.618 a**	**0.559 a**	**0.591 a**	**0.585 b**	**0.597 a**	**0.616 ab**	**0.611 ab**	**0.593 bc**	**0.618 bc**
XCU 43-0-0 SGN 190	**0.619 a**	**0.562 a**	**0.593 a**	**0.588 b**	**0.601 a**	**0.623 a**	**0.632 a**	**0.595 b**	**0.623 ab**
XCU 43-0-0 SGN 260	**0.623 a**	**0.573 a**	**0.601 a**	**0.601 ab**	**0.612 a**	**0.637 a**	**0.635 a**	**0.608 ab**	**0.636 ab**
Untreated control	**0.538 b**	**0.507 b**	**0.535 b**	**0.526 c**	**0.536 b**	**0.555 b**	**0.536 b**	**0.535 c**	**0.558 c**
msd p=0.05	**0.050**	**0.042**	**0.045**	**0.046**	**0.050**	**0.063**	**0.077**	**0.059**	**0.062**
	66	**70**	**72**	**77**	**80**	**84**	**91**	**94**	**105**
Polyon 42-0-0 SGN 250	**0.670 a**	**0.586 a**	**0.606 a**	**0.600 a**	**0.588 a**	**0.597 a**	**0.674 a**	**0.579 a**	**0.598 a**
Polyon 43-0-0 SGN 190	**0.640 ab**	**0.554 a**	**0.570 a**	**0.550 ab**	**0.561 a**	**0.571 ab**	**0.649 ab**	**0.556 ab**	**0.571 ab**
Polyon 43-0-0 SGN 250	**0.641 ab**	**0.559 a**	**0.573 a**	**0.545 ab**	**0.560 a**	**0.568 ab**	**0.643 ab**	**0.557 ab**	**0.565 ab**
ProTurf 40-0-0	**0.610 ab**	**0.538 ab**	**0.551 ab**	**0.549 ab**	**0.533 ab**	**0.535 abc**	**0.605 abc**	**0.527 abc**	**0.538 bc**
ProTurf 44-0-0 SGN 190	**0.620 ab**	**0.543 a**	**0.560 ab**	**0.533 ab**	**0.535 ab**	**0.552 ab**	**0.616 ab**	**0.537 abc**	**0.550 ab**
ProTurf 44-0-0 SGN 250	**0.625 ab**	**0.536 ab**	**0.553 ab**	**0.525 ab**	**0.528 ab**	**0.535 abc**	**0.602 bc**	**0.529 abc**	**0.545 bc**
Urea	**0.603 ab**	**0.514 ab**	**0.533 ab**	**0.499 ab**	**0.516 ab**	**0.520 bc**	**0.589 bc**	**0.521 abc**	**0.528 bc**
XCU 43-0-0 SGN 190	**0.598 bc**	**0.518 ab**	**0.535 ab**	**0.528 ab**	**0.518 ab**	**0.520 bc**	**0.586 bc**	**0.508 bc**	**0.528 bc**
XCU 43-0-0 SGN 260	**0.615 ab**	**0.538 ab**	**0.551 ab**	**0.522 ab**	**0.528 ab**	**0.533 abc**	**0.603 abc**	**0.522 abc**	**0.535 bc**
Untreated control	**0.531 c**	**0.453 b**	**0.471 b**	**0.434 b**	**0.464 b**	**0.466 c**	**0.537 c**	**0.482 c**	**0.495 c**
msd p=0.05	**0.068**	**0.088**	**0.089**	**0.121**	**0.075**	**0.074**	**0.072**	**0.061**	**0.050**

[1]Normalized-difference vegetation index: mean of 4 replicates; means within columns followed by the same letter are not significantly different (Tukey's HSD test, p=0.05). Readings in bold are from dates with significant treatment effects.

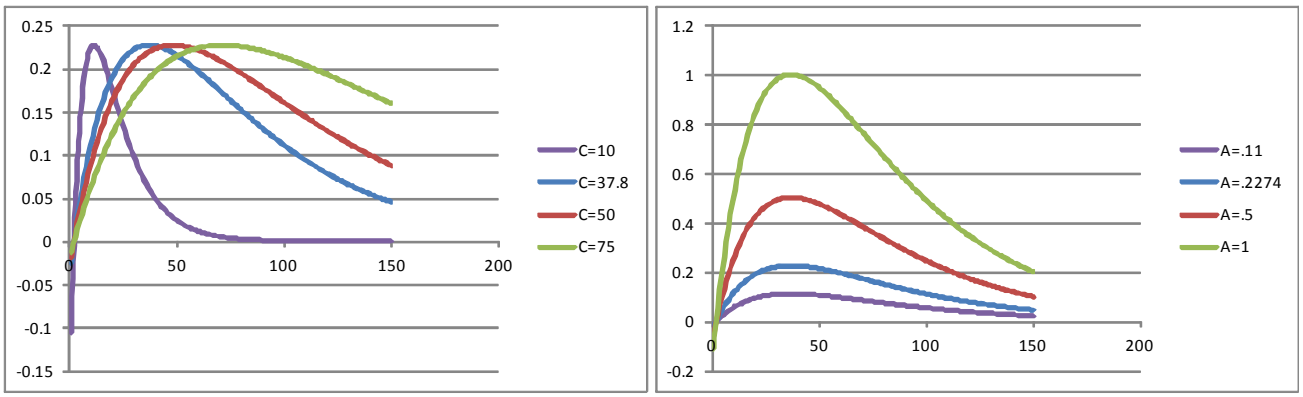

Figure 5. Families of curves of the function $\Delta NDVI = 4 \star A \star e^{(-DAT/C)} \star (1 - e^{(-DAT/C)})$ illustrating the effects of varying the parameters A and C.

treatments had significantly higher canopy reflectance values than the untreated control. By 56 DAT the treatment had begun to disappear from the Urea treatment, and by 70 DAT a number of the treatments had NDVI values not significantly different from the control.

The ΔNDVI values, when plotted over time, allowed some differentiation among the fertilizer treatments in terms of release characteristics as detected by canopy reflectance. Replicate mean values of ΔNDVI were tested against various curves to determine which functions had potential to adequately describe the responses. The online curve fitting and surface fitting web site at www.zunzun.com was used to investigate families of curves. One of the best functions to fit the data was a compound exponential function $\Delta NDVI = 4 \star A \star e^{(-DAT/C)} \star (1-e^{(-DAT/C)})$, in which there are two fitted parameters: A, which varies with maximum ΔNDVI, and C, which varies with days to maximum ΔNDVI (Figure 5). The suitability was judged based on the combination of goodness of fit, minimum number of parameters, and interpretability of the parameters

The ΔNDVI values for each treatment were fitted to these curves using GraphPad Prism, and the estimates of A and C for each treatment were compared using ANOVAs. The parameter estimates of the fitted curves are shown in Table 4 and Figure 6, and the fitted curves are shown in Figures 7-9.

Table 4. Multiple comparisons of estimated parameters for fitted curves of ΔNDVI.

Treatment	A		C	
Polyon 42-0-0 SGN 250	0.109	b[1]	146.9	b
Polyon 43-0-0 SGN 190	0.102	b	62.1	a
Polyon 43-0-0 SGN 250	0.097	ab	64.5	a
ProTurf 40-0-0	0.074	a	53.7	a
ProTurf 44-0-0 SGN 190	0.084	ab	54.9	a
ProTurf 44-0-0 SGN 250	0.094	ab	43.2	a
Urea	0.083	ab	36.8	a
XCU 43-0-0 SGN 190	0.084	ab	38.0	a
XCU 43-0-0 SGN 260	0.088	ab	43.4	a

[1] Parameters followed by the same letter are not significantly different (Tukey's Multiple Comparison Test, p=0.05)

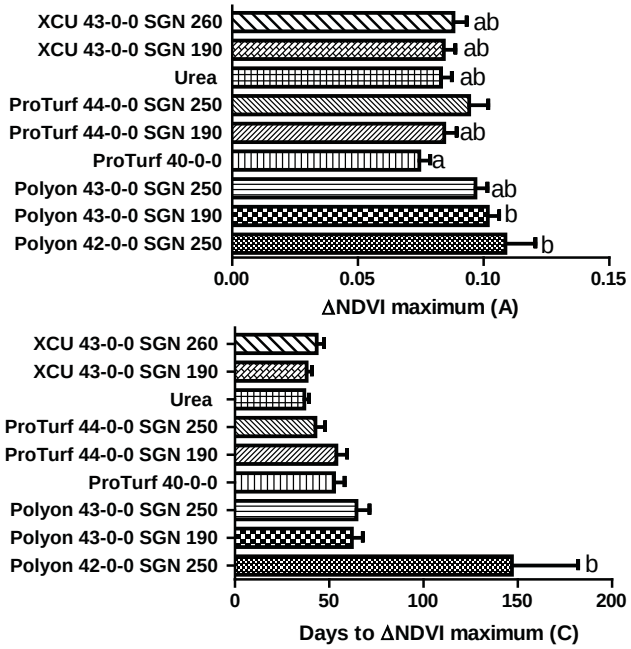

Figure 6. Parameters A and C for curves fitted to fertilizer response as estimated by ΔNDVI. Parameter estimates are all significantly different except where a common letter is present on the bars (Tukey's multiple comparison test, p=0.05).

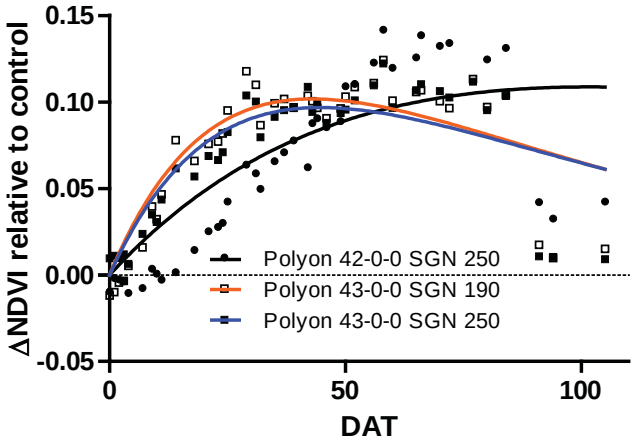

Figure 7. Curves fitted to fertilizer response as estimated by ΔNDVI. See Table 4 for estimates of A (max ΔNDVI) and C (days to max ΔNDVI). Points are means of 4 replicates; curves were fitted to replicates.

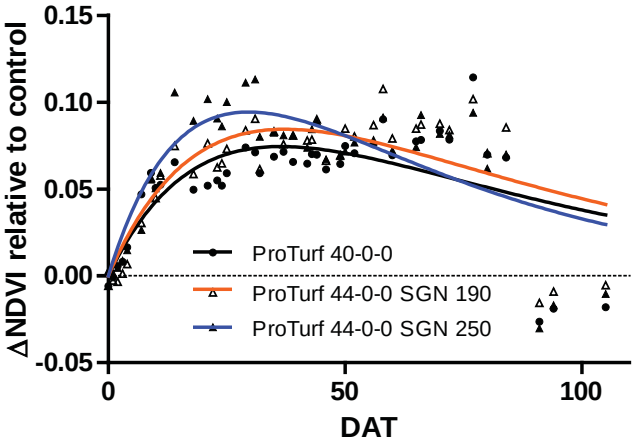

Figure 8. Curves fitted to fertilizer response as estimated by ΔNDVI. See Table 4 for estimates of A (max ΔNDVI) and C (days to max ΔNDVI). Points are means of 4 replicates; curves were fitted to replicates.

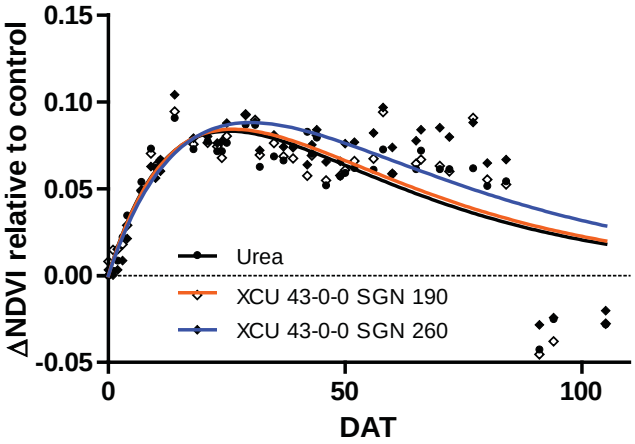

Figure 9. Curves fitted to fertilizer response as estimated by ΔNDVI. See Table 4 for estimates of A (max ΔNDVI) and C (days to max ΔNDVI). Points are means of 4 replicates; curves were fitted to replicates.

Shoot growth. Clippings were collected periodically to estimate shoot dry matter accumulation. Plots were mowed to 40 mm and then 5 – 7 days later clippings were collected from a 0.35 m^2 strip (Figure 10). Although there were significant differences in growth by 4 weeks after treatment, the noisiness of the data meant that there was a lot of overlap in the means (Table 5). The general pattern of increase and decline in growth rates was similar to the response curves as estimated by ΔNDVI. Comparing the plot means for growth with ΔNDVI shows this relationship (Figure 11), and ΔNDVI appears to be a good proxy for shoot growth under these conditions.

DISCUSSION AND CONCLUSIONS

All treatments gave a significant improvement in colour and growth compared to the untreated control. The fertilizer effects were observable within a week after treatment by the canopy reflectance data, and persisted in significant amounts until data collection ceased for the season (15 weeks after treatment). The average gain of fertilized treatments over control was about 2 ranks on the visual colour rating scale (6 to 8), or about 0.10 units on the canopy reflectance index. The untreated control plots were at an acceptable colour and quality level (>5) through most of the trial. There was no strong or consistent pattern date by date distinguishing the fertilizer treatments from one another, either in visual ratings, or canopy reflectance, or growth. Using the release curves fitted to the seasonal pattern of "NDVI suggests that the ranking of the fertilizer treatments for strength of response (A) was ProTurf 40-0-0 < Urea ≤ ProTurf 44-0-0 SGN 190 ≤ XCU 43-0-0 SGN 190 < XCU 43-0-0 SGN 260 < ProTurf 44-0-0 SGN 250 < Polyon 43-0-0 SGN 250 < Polyon 43-0-0 SGN 190 < Polyon 42-0-0 SGN 250. Similarly, the ranking of the treatments for days to maximum release (C) was Urea < XCU 43-0-0 SGN 190, ProTurf 44-0-0 SGN 250 < XCU 43-0-0 SGN 260, ProTurf 40-0-0 < ProTurf 44-0-0 SGN 190, Polyon 43-0-0 SGN 190 < Polyon 43-0-0 SGN 250, Polyon 42-0-0 SGN 250.

Table 5. Dry matter accumulation.

Treatment	14 DAT	31 DAT	44 DAT	58 DAT	93 DAT
			g m^{-2}		
Polyon 42-0-0 SGN 250	3.92	2.86 ab	3.07 ab	2.39 a	2.49 a
Polyon 43-0-0 SGN 190	4.90	3.62 a	3.26 a	1.87 abc	2.03 ab
Polyon 43-0-0 SGN 250	5.65	3.94 a	3.77 a	1.88 abc	1.65 ab
ProTurf 40-0-0	5.12	2.40 ab	3.07 ab	1.35 abc	1.12 ab
ProTurf 44-0-0 SGN 190	6.47	3.70 a	3.59 a	2.12 ab	1.55 ab
ProTurf 44-0-0 SGN 250	6.29	4.05 a	3.52 a	1.59 abc	1.23 ab
Urea	5.92	2.92 ab	2.66 ab	1.10 bc	0.87 b
XCU 43-0-0 SGN 190	5.26	2.73 ab	2.80 ab	1.68 abc	1.48 ab
XCU 43-0-0 SGN 260	4.70	2.97 ab	2.86 ab	1.63 abc	1.35 ab
Untreated control	3.81	1.24 b	1.39 b	0.64 c	0.66 b
msd p=0.05	NS	2.33	1.70	1.27	1.43

[1] Clippings collected from 0.38 x 0.94 m strip of each plot, mowed at 42 mm after 5-7 days of growth.

Figure 10. Clipping collection: border strips were mowed short (<40 mm) and clippings were then collected from a 0.94 m strip lengthwise in each plot using a Gardena electric reel mower set at 42 mm height of cut.

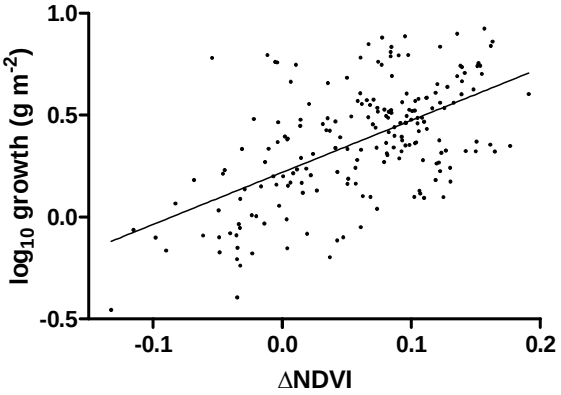

Figure 11. Relationship between increase in canopy reflectance and shoot growth as estimated by dry matter accumulation. Points are plot means; all clipping collections data are plotted. Dry matter accumulation is log-transformed to give a linear relationship.

Differences in growth began to be apparent when fertilizer response was near its maximum, about 4 weeks after treatment, and continued to be significant until the end of the season. At the peak fertilizer effects the treatments with the highest growth rate had three to four times as fast a rate as the untreated control.

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